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Analysis of Computation Electromagnetic Modeling Techniques

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ABSTRACT

Computer techniques have revolutionized the way in which electromagnetic problems are analyzed. Antenna and microwave engineers rely heavily on computer methods to analyze and help evaluate new designs or design modifications. In this section, some of electromagnetic modelling techniques which are widely used in CEM will be briefly discussed along with their advantages and disadvantages

Keywords

S-parameter, Microstrip notch, Stepped waveguide, Time domain, Method of Moment, Finite Element method.

1. INTRODUCTION

The industrial and engineering demands for sophisticated electromagnetic modeling for a wide range of applications are continuously increasing. This ever increasing demand has made computational electromagnetics into an "industry" of its own, involving a large number of researchers in academic, government and industrial laboratories. As a consequence, the number of methods, techniques, algorithms and their variations involved with computational electromagnetics have become almost innumerable. Many criteria may be used to classify the techniques involved in CEM, like the domain in which they are operating (time/frequency), the type of equations on which they are based (integral/differential), the dimensionality of the problem (two-dimensional/three-dimensional) etc.[1]. However it is extremely difficult to distinctly classify the techniques based on such criteria, as many of them share common features or are interconnected with each other [2]. Some of the state-of-the-art numerical techniques (methods) which are widely used in CEM will be briefly discussed along with their advantages and disadvantages.

The methods are classified into:

i. Frequency Domain Methods (Time Harmonic)
   a) Method of Moment (MoM)
   b) Finite Element Method (FEM)
ii. Time domain methods (Transient)

This includes; Finite Difference Time Domain (FDTM) method

2. GENERAL OVERVIEW

I. Method of Moments

The method of moments (MoM), also known as the method of weighted residuals, is widely used in CEM, especially for the antenna engineering. Development of this method was initiated in Russia. It has been successfully applied to a wide variety of electromagnetic problems like the thin wire antennas and arrays, scattering problems, analysis of microstrips, Wave guide transition, etc. [3]. In this method, an appropriate integral equation is derived for the problem under consideration. At the next step this integral equation, which typically involves surface currents, is discretized into a matrix equation using proper basis functions and weighting functions. Afterwards, the matrix elements are evaluated and finally the corresponding linear system of equations is solved using a suitable solver. From the solution, the parameters of interest are evaluated. Usually the MoM is applied in the frequency domain, so the matrices involved in this method are fully populated with complex valued entries. However, usage of the MoM in the time domain is very limited till now, mainly for the stability related issues.

Advantages.

a) Highly conducting surfaces can be treated very efficiently. With this method only the surfaces are needed to be discretized - it is not needed for the whole computational volume. This makes the method computationally efficient for the problems with small surface/volume ratio
b) The radiation condition is automatically incorporated, requiring no additional computational efforts.
c) Extension of this method towards stratified media can efficiently be formulated increasing its applicability.

Disadvantages:

a) It cannot handle the electromagnetically penetrable materials very efficiently.
b) Computational requirements for the MoM increase very sharply with increasing frequency.

II. Finite Difference Time Domain

(FDTD) Method

The finite difference time domain (FDTD) method is based on direct discretization of Maxwell's equations in their difference form. It is one of the most popular techniques based on finite differences. The application of finite differential method in computational electromagnetics was initiated around 1920 under the title "the method of squares". In general, the finite difference techniques approximate Maxwell's equations by difference equations [4]. A number of finite difference schemes exist with different accuracies, convergence and complexities in the approximation of the differentials. Under these schemes, the value of the dependent variable at a point in the solution region is related to the values at some neighboring points. There are plenty of finite difference techniques applied in CEM besides the FDTD method e.g. the finite difference frequency domain (FDFD) method, finite volume time domain (FVTD) method etc. All of these methods are quite similar in formulation, sharing the common advantages and disadvantages. The FDTD method was first proposed by Yee in 1966. Due to the higher computational cost and the difficulty to model open problems, it was not widely used at the beginning. Later, advent of the techniques like the absorbing boundary condition (ABC), perfectly matched layers (PML) etc. have made this method capable to model open problems [5]. The exponential increment in the computational power have made this method extremely popular in the recent days.

There are several advantages of the FDTD method:

a) The method relies on a versatile and simple modeling technique. This makes the application of this method very simple and straightforward.
b) Being a time domain technique, a broadband frequency response can be obtained from a single simulation.
c) Since this method computes the electric and magnetic fields at each grid point, it is possible to have an animated view of the fields. This can provide a very useful insight for design and optimization of microwave devices.
d) Modeling of inhomogeneous media of magnetic media can be readily realized with FDTD.

The main weakness of the FDTD method is that the entire computational domain has to be discretized resulting in very large computational domains for some problems. This leads to very long computation times for such problems. This problem becomes severe for large structures containing some tiny complex features.

III. Finite Element Method (FEM)

The finite element method (FEM) is a very powerful and versatile numerical method capable of modeling complex geometries and inhomogeneous media [6]. However the FEM formulation is more complex than the MoM or the FDTD method. The FEM was originated from the need to solve complex elasticity, structural analysis problems in civil and aeronautical engineering [3].

The FEM can be formulated mainly with two approaches:

a) Using the variational analysis and
b) Using the method of weighted residuals.

In the first approach, the partial differential equation form of the Maxwell's equations is chosen.

Afterwards a variational function is found whose external point, subject to certain boundary condition, corresponds with the solution of the problem.

Advantages associated with the FEM:

a) With this method, complex geometries and inhomogeneous media can be straightforwardly and conveniently treated.
b) With FEM, each mesh element can be defined independently. Thus, a large number of fine mesh elements can be used in regions with complex geometry and fewer, larger elements can be used in relatively simpler or open regions.

Disadvantages of FEM:

a) It does not include the radiation condition. As a consequence, implementation of absorbing boundaries are musts to solve problems with open boundaries.
b) For large three dimensional problems, the FEM mesh can be very complex. In some cases the required time to mesh a certain structure can be larger than the time required for the field commutation.
c) The FEM method is more complex to implement than the FDTD method.

3. METHODOLOGY, SIMULATIONS AND RESULTS

The analysis made on two observations:

a) S-parameter coupling in a stepped waveguide section and
b) Simple microstrip notch filter

I. S-parameter coupling in a stepped waveguide section.

In this analysis we considered transition from Ku-band to X-band. The modal is first simulated using the MoM on waveguide port and then using the FEM on modal ports.

The following variables were used:

- Fmin= 9.4872 Ghz
- Fmax= 20 Ghz
- Width of ku-section (a1) =15.8
- Width of x-section (a2) =22.9
- Height of the ku-section (b1) = 7.9
- Height of the x-section (b2) = 10.2
- Length of the ku-section (l1) =12
- Length of the x-section (l2) =12

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The critical frequency for the choosen H mode in the smaller ku-band waveguide is fc=9.4871 Ghz. The S-parameter are computed from this cut-off frequency up to 15 Ghz using adaptive frequency sampling.

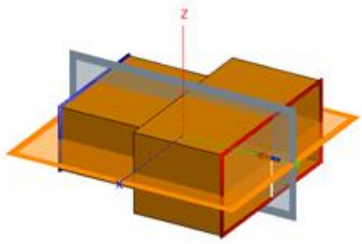

Figure 1: 3D view of a stepped waveguide section

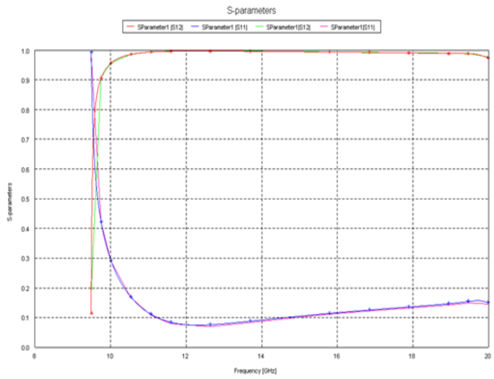

Figure 2: S-parameter coupling in a stepped waveguide section- MoM and FEM

II. Simple microstrip notch filter

The filter solved using Method of Moment (MoM) and the finite element method (FEM).

Variables used:

- fmax = 4e9 (Maximum frequency.)
- fmin = 1.5e9 (Minimum frequency.)
- epsr = 2.33 (Substrate relative permittivity.)
- shielding_height = 11.4 (Height of the shielding box.)
- substrate_height = 1.57 (Substrate height.)
- gnd_length = 92 (Length and width of substrate.)
- port_offset = 0.5 (Inset of the feed point.)
- strip_width = 4.6 (Width of the microstrip sections.)
- strip_offset = 23 (Offset of the microstrip from the ground edge.)
- stub_length = 18.4 (Length of the stub.)
- stub_offset = 41.4 (length from the ground edge to the stub.)

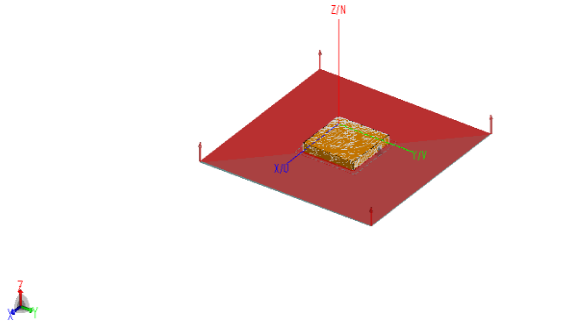

Figure 3: 3D view of Simple microstrip notch filter

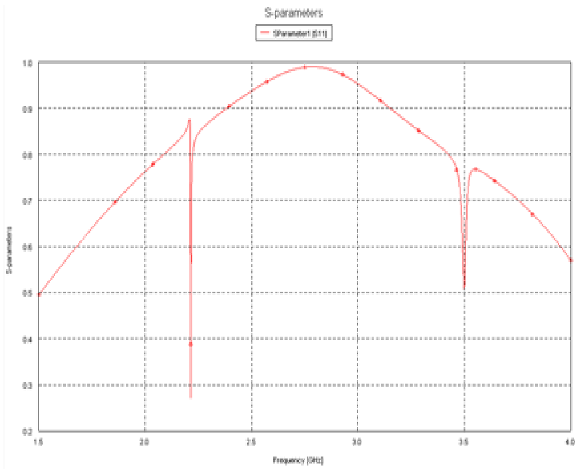

Figure 4: S-parameter of a Simple microstrip notch filter- Method of Moment

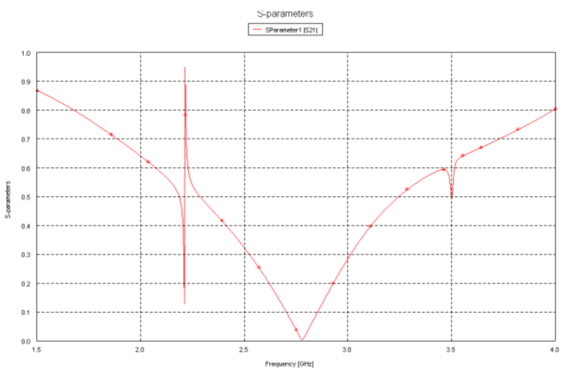

Figure 5: S-parameter of a Simple microstrip notch filter- Finite Element Method

4. CONCLUSION

Numerical Methods allow us to solve real life EM problems

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(within certain limits). They form the engine(s) of electromagnetic simulators. Electromagnetic simulators are not merely Maxwell equation solvers, but powerful simulation and design tools with visualization capabilities. FEM modelling is ideal in these instances because FEM solution matrices are sparse, where MoM matrices are densely populated. As a result FEM matrices are significantly more scalable with an increase in frequency

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